X. *An Account of ſome Appearances attending the Converſion of caſt into malleable Iron. In a Letter from* Thomas Beddoes, *M. D. to Sir* Joſeph Banks, *Bart. P. R. S.*

Read March 24, 1791.

SIR,

YOU are undoubtedly well apprized of an alteration lately introduced into our manufactories of iron, in conſequence of which the reverberatory has been ſubſtituted in the place of the finery furnace. The new proceſs is capable of being indefinitely varied. I have lately been favoured with an opportunity of obſerving one of theſe variations with every advantage I could deſire. As in this method the changes undergone by the metal during the firſt ſeries of operations lie perfectly open to inſpection, a ſhort deſcription of them may not perhaps be unworthy the notice of philoſophical chemiſts. Allow me to premiſe further, that I did not content myſelf with a ſingle examination; and, for the ſake of greater accuracy, I took minutes of the phænomena, and of the time when they occurred. A very intelligent workman was at the ſame time directed to anſwer all my queſtions, ſo that I enjoyed the benefit of his experience alſo.

In ſomewhat more than half an hour after it was put in, the charge conſiſting of 2½ cwt. of grey pig iron was nearly melted. The workman now began to ſtir the liquid maſs: for

for this purpoſe he uſed ſometimes an iron lever, and ſometimes a kind of hoe; but he firſt turned the flame from off the metal, which is done by letting down a damper upon the chimney correſponding to that with which ordinary reverberatory furnaces are provided, and by raiſing the damper of a ſecond chimney, which proceeds immediately from the fire-place, and carries off the flame, current of air, &c. without allowing it paſs into the body of the furnace.

In 50 minutes from the commencement of the operation, the metal had become in conſequence of the conſtant ſtirring looſe and incoherent; it appeared about as ſmall as gravel; it was now alſo ſtiff, and much cooled.

55 m. from the ſame period, flame turned on again. Workman keeps ſtirring and turning over the metal; in 3 m. it becomes ſoft and ſemi-fluid; flame turned off; the hotteſt part of the maſs begins to heave and ſwell, emitting a deep blue lambent flame. The workman calls this appearance fermentation.

1 hour 1 m. blue flame breaking out over the whole maſs; heaving motion alſo general.

1 h. 13 m. metal full as hot, or, as the workman and myſelf both judged, rather hotter than at the inſtant the flame was turned off, though it is now a quarter of an hour ſince.

1 h. 18 m. where there is no heaving and no blue flame the maſs is ſenſibly cooler, and only of a dull red heat.

1 h. 20 m. workman obſerves, that the metal ſticks leſs to his tools. Pig-iron, he ſays, faſtens upon it immediately, and muſt be ſhaken off by ſtriking the other end with an hammer; as it approaches more and more towards *nature* (malleable iron) it adheres leſs; and when the tools come clear up out of the maſs, he judges it to be fermented enough.

1 h. 23 m. little heaving or blue flame; metal ſtiffer, and of a dull red; flame turned on and ſoon off again.

1 h. 26 m. by conſtant ſtirring the metal is become as fine as ſand. Workman remarks, that the flame, which reappears over the whole maſs, looks more kindly. It is evidently of a lighter blue colour.

1½ h. flame turned on and ſoon off again. Maſs ferments ſtrongly. Hiſſing noiſe heard: this noiſe was diſtinguiſhable in ſome degree ever ſince the blue flame and heaving motion became viſible, but always faint till now.

1 h. 40 m. leſs blue flame.

1 h. 48 m. flame twice turned on and off in this interval. Metal now clots, ſtands wherever it is placed, without any tendency to flow, and no liquid pig iron now remains in the baſon of the furnace; the maſs has been conſtantly ſtirred and turned over.

1 h. 50 m. a little finery cinder appears boiling up amid the maſs. Workman attributes the increaſe of the hiſſing to this.

1 h. 53 m. ſcarce any perceptible blue flame or heaving. All the metal is now gathered into lumps, which the workman beats and preſſes with an heavy-headed tool. He brings them ſucceſſively into the hotteſt part of the furnace, into which the flame has been admitted. He now ſtops the port hole in the door at which he had introduced his tools, and applies a fierce flame for 6 or 8 minutes; the metal is then rolled.

Theſe appearances, at leaſt the moſt intereſting of them, ſeem to admit of an eaſy explanation; and I offer the following obſervations as ſupplemental to thoſe for which we are already indebted to the Swediſh and French chemiſts on this important branch of metallurgy. I aſſume the following propoſitions as already proved by theſe philoſophers. 1. That caſt iron

iron is iron imperfectly reduced, or, in other words, that it contains a portion of the basis of vital air, the oxygène of M. LAVOISIER. 2. That it contains a portion of plumbago, with which grey cast iron most abounds. 3. That plumbago consists of iron united to charcoal. 4. That fixed air, which I would rather call carbonic acid air, consists of oxygène and the constituent parts of charcoal.

The heaving or swelling motion, so conspicuous in the process, is doubtless owing to the discharge of an elastic fluid; and the lambent deep blue flame, breaking out in spots over the whole surface, shews, that this elastic fluid is an inflammable gas of the heavy kind. That no doubt might be left upon the former of these circumstances, I directed the workman to take out, at two different periods, a quantity of the metal where it was working most strongly. Both proved, on examination, to be spungy, cellular, and full of bladder holes.

The heavy inflammable air, I imagine, is produced in this manner. The oxygène of the imperfectly reduced metal combines with the charcoal to form fixed air; at the same time another portion of charcoal is thrown into an elastic state, that is, into inflammable air, and burns on the surface with a very deep blue flame, on account of the admixture of fixed air. The heat which is so obviously generated in the mass at the beginning of the fermentation, I attribute to the combination of the oxygène and charcoal; a fact which, with several others as I have already remarked on another occasion *, shews, if not the falsehood, at least the imperfection of the modern doctrine on the subject of heat. The acidifying principle, it would appear, has some power of generating heat independant of its condensation. Here abundance of elastic matter is

* Chemical opinions of a philosopher of the last century.

dif-

discharged; yet, notwithstanding the heat absorbed by its formation, and that which flows out of the metal in all directions, the whole mass becomes hotter. The oxygène cannot be supposed to have much specific or latent heat, because it undoubtedly exists in the iron in a very condensed state. Neither does the appearance of the mass allow me to ascribe this generation of heat to the burning of the inflammable air at the surface, as will also be immediately evident for another reason. The less deep blue colour of the flame at a subsequent period in the operation is probably owing to the absence of fixed air, or at least to its being produced more sparingly, the oxygène being now nearly consumed. It will not appear surprizing, that the oxygène in this case should be consumed before the charcoal, if it be considered, 1. that grey iron contains a large portion of plumbago; and, 2. that fixed air contains a much larger quantity of oxygène than of charcoal; near three times as much, according to our best experiments on its formation: so that I ascribe the subsequent fermentation accompanied with the lighter coloured flame almost entirely to the conversion of the charcoal into an elastic fluid. A very experienced philosopher, I am well aware, has asserted, that water is necessary to this conversion; an opinion concerning the justness of which I have long entertained great doubts. Whenever I have distilled charcoal *per se*, I have found the first portions of gas to contain fixed air; an appearance owing, as I believe, to the decomposition of water absorbed from the atmosphere; but, after continuing the process for some time, there has still been a production of inflammable air; but from this neither lime-water nor milk of lime would absorb any portion, though when fired with vital or common air, it would produce fixed air; and if moisture was added to the charcoal, inflammable

and fixed air would be generated anew. Moreover it appears, from the experiments of Dr. AUSTIN and ſome others, that charcoal conſiſts of the hydrogène and azote of the French chemiſts. How far it may be difficult or impoſſible entirely to convert charcoal in its ordinary ſtate into gas, is a point I wiſh to ſee more fully illuſtrated by future experiments. At preſent it ſeems obvious, that the circumſtances of the operation I have deſcribed are particularly favourable to this converſion: for, 1. not to mention the violence of the heat, we have this ſubſtance in a very attenuated ſtate, ſo that, very probably, the expanſive power of fire is very little, if at all, counteracted by the attraction of coheſion, which cannot be ſaid in the caſe of the moſt minute mechanical diviſion we can effect. 2. The attraction of the particles of the iron for one another will produce an effort to extrude the intermixed particles of charcoal, and thus enable it more readily to aſſume the elaſtic form.

Now, during the continuance of the lighter coloured blue flame, the maſs, as I obſerved, ſhews no power of generating heat within itſelf; a circumſtance which indicates that the heat produced in the former part of the operation does not depend on the burning of the gas at the ſurface; and I think inſpection will ſatisfy any one that it is produced in the heart of the maſs. It may indeed be objected, that the metal, now brought nearer to the ſtate of malleable iron, may require a greater ſupply of heat to keep it at the ſame temperature. It is leſs fuſible, as we are well-aſſured. By referring back to the minutes you will obſerve, how very often it was neceſſary to turn the flame upon the maſs during this ſecond fermentation in order to keep it in a ſtate in which it could be worked.

The very copious production of elaſtic fluids during an hour, and often during a much longer ſpace, for in this inſtance the

procefs was remarkably fuccefsful and fhort, does not feem favourable to a late ingenious hypothefis, according to which water is the embodying principle of all elaftic fluids. I have never indeed confidered this as very probable, and, after the obfervations I have related, I fee no means of defending it. Will it be faid, that the pig iron, as being in fome fort a calx of iron, contains water?

In annealing crude iron, with or without charcoal, it is well known to increafe in all its dimenfions. I have feen bars originally ftraight bent like an S, when long expofed to heat in circumftances where they could not extend themfelves endways. I fuppofe this phænomenon may be owing to a very fmall beginning of this fermentative motion, which acts as an internal principle of expanfion. Caft iron bars, not in contact with charcoal, would, according to this fuppofition, by long annealing lofe of their weight; or if the heat was too low for the elaftic fluid to be difcharged from their fubftance, they would probably blifter like fteel: an appearance undoubtedly owing to the generation of air. Mr. HORNE, in his Effay on Iron, fomewhere remarks, that on opening thefe blifters he has heard a whiftling noife as of air rufhing out.

During the whole of this procefs, frequent jets of white fparks, of a dazzling brightnefs, played from the furface of the metal. They would have afforded an extremely beautiful fpectacle but for the inconvenience of looking on fo hot a mafs. They arofe, no doubt, from the burning of fmall portions of iron.

The effect of fo much ftirring as I have noted down does not require to be explained.

The workman was clearly of opinion, that the fermentation of hard or white crude iron is lefs than of grey in this

 procefs;

proceſs; a fact which perfectly coincides with the preceding obſervations, ſince that ſpecies contains leſs plumbago, or in other words leſs matter fit to produce elaſtic fluids.

In order to prove the extrication of fixed air during the fermentation of the metal, I once thought of introducing lime-water in an iron veſſel within the body of the furnace; but when I conſidered that the fire-place was not divided by any partition from the body of the furnace, and that the whole building was full of burned air, I omitted the experiment from a perſuaſion that, even if the lime-water ſhould become turbid, the fixed air might come from another ſource.

I was not unmindful of the ſulphur which exiſts, as I have reaſon to believe, in every form of iron manufactured with coaks. I cannot, however, aſcribe any of the effects I obſerved to its preſence. There can be little doubt, that ſome portion was perpetually extricated with the inflammable air during the whole proceſs; for on diſſolving pieces of the ſtamped, or rather the rolled iron in weak muriatic acid, ſilver held in the extricated air was tarniſhed as much and as ſoon as by air from ſpecimens taken out of the furnace at different times during the proceſs. I could not but conclude, that the tarniſhing matter came from the iron, when I found the air from a ſolution of zinc in the ſame acid, incapable of producing the colour upon ſilver. The appearance, the want of a martial aſtringent taſte, and the diſſolving action of cauſtic alkali, led me to conclude, that the colour in each experiment with iron was derived from ſulphur.

I leave it to the adherents of phlogiſton to accommodate theſe phænomena to their doctrine; conſidering it, for my own part, as ſuperfluous to beſtow any further attention upon a

ſyſtem which, after a long diſcuſſion, has been fully refuted in all its modifications, and which indeed ſeems on the eve of being univerſally abandoned.

I have the honour to be, &c.

THOMAS BEDDOES.